PROMETHEUS

OR BIOLOGY AND THE ADVANCEMENT OF MAN

H. S. JENNINGS

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TO-DAY AND TO-MORROW

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BIOLOGY AND THE ADVANCEMENT OF MAN

BY

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The nature of man is not what he is born as, but what he is born for.—*Aristotle.*

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PREFACE

THE exposition of the relations of heredity and environment here given differs from that frequently set forth in the name of genetic science. I wish to emphasize, therefore, that it is presented as the outgrowth and fruit of the most orthodox genetics of the straitest sect of experimental Mendelism. It is designed as a statement of the present situation of scientific knowledge. The writer is not one of those who hold that inspired thinking may take the place of experiment in such matters. The only conclusions at which we can rest are generalized statements of the

observed facts. Such it is believed are here set forth.

The beginnings of knowledge often point to clear and simple conclusions that range themselves in the pattern of some obvious theory. Such conclusions are drawn with confidence: they are set down in the text-books; they are fixed in the mind; they acquire authority; they become part of science. Only details, illustrating and applying these principles, require, it seems, yet to be discovered. As the details are worked out, they are ranged as best may be under the theory; if some of them fit it awkwardly or not at all, these are but laid aside as indigestible. In time there comes to be a great store of facts that do not fit the accepted generalizations. But to revise the generalizations—*hic labor, hoc opus est;*

this is not to be lightly undertaken; it throws all into confusion; it discredits what science has pronounced; it is avoided. Theory and facts become hopelessly at variance, yet they continue to rest side by side in a single framework. Such has been the course of events in the science of genetics. The hen of Mendelian theory has hatched a brood of swans. She would fain claim them as her own, but they have lost all semblance of chicks.

PROMETHEUS

I. The Question

Man's recent deplorable activities have brought forth in swelling chorus the question: "What's the matter with man?" And no antiphonal choir responds: "He's all right!" Rather rises the farther question: "What must be done about it? How can man be so changed that he will no longer pursue his disastrous practices?"

Other organisms have been improved —if by improvement is meant alteration to make them resemble a particular

type that is considered better. How is this done? And can the same method be employed with man?

Men and other organisms begin their independent existence as minute bits of material; as cells. All those of the same species appear much alike. But they enlarge, transform and develop into individuals that are very diverse. Some are much more desirable than others; for all agree that it is more desirable to be normal than deformed or feeble-minded. There is, indeed, a great series of grades, from the fool up to Shakespeare; though as to the ranking of the intermediate grades, no consensus can be traced.

The underlying biological questions are: How does it happen that some of these bits of material develop into one sort of an individual, some into other

sorts? And can anything be done to make a larger proportion of them, or all, develop into desirable individuals? Much has been learned on these questions since the key to an understanding of the *rôles* of inheritance and environment in development was recovered just twenty-five years ago. Knowledge has moved rapidly and has, indeed, changed fundamentally within the last ten years, altering the picture as to the relations of heredity and environment. What has gotten into the popular consciousness as Mendelism —still presented in the conventional biological gospels—has become grotesquely inadequate and misleading; particularly have its seeming implications as to the trivial *rôle* of environment come into a new light.

II. The Biological Background

HEREDITY AND ENVIRONMENT

What happens in any object—a piece of steel, a piece of ice, a machine, an organism—depends on the one hand upon the material of which it is composed; on the other hand upon the conditions in which it is found. Under the same conditions objects of different material behave diversely; under diverse conditions objects of the same material behave diversely. Anything whatever that happens in any object has to be accounted for by taking into consideration both these things.

Neither the material constitution alone nor the conditions alone will account for any event whatever; it is always the combination that has to be considered.

Organisms are like other objects in this respect; what they do or become depends both on what they are made of and on the conditions surrounding them. The dependence on what they are originally made of we call heredity. But no single thing that the organism does depends alone on heredity or alone on environment: always both have to be taken into account.

What an organism is first composed of comes directly from its parents; this is the reason why dependence on that composition has been called heredity. But this habit of speech has led to conceiving heredity as something in

itself, an entity, a "force," something that itself does things—an error that has induced clouds of misconception. Possibly we should be better off with no such concept as heredity; then analysis would be correctly directed toward understanding, in organisms as in other things, in what ways there is dependence on the stuff they are made of: in what ways on the conditions in which that stuff is found.

As to the dependence on the stuff that they are made of, research has shown that the substances passed from parent to offspring, giving rise to the phenomena of inheritance, are a great number of discrete packets of diverse chemicals, embedded in a less diversified mass of material. The masses formed by the groupings of these packets are visible under the microscope as the chromo-

somes. The number of different kinds of packets that go into the beginning of any individual is very great, running into the hundreds or thousands. They are not massed in a haphazard way, but are arranged in a definite manner; so that the young organism is like a well-organized chemical laboratory with many re-agents so arranged in containers as to react with one another in an orderly way, producing a definite and harmonious result.

Development, we know, consists in this orderly interaction of these substances with one another, with the rest of the cell body or cytoplasm; and with the oxygen, food and other chemicals brought into the cell from outside; all under the influence of the physical agents of the environment. The final result—what the individual becomes—

is dependent upon all these things; a change in any of them may change the result.

The disposition of the chemical packets, or genes, is known to be at the beginning that of a double serial arrangement like a pair of strings of beads; each chemical has its precise and practically invariable place in the series. For each packet in one of the two strings there is a corresponding packet in the other, so that the whole forms a set of pairs of packets. The two corresponding packets of one pair may both contain the same chemical. More commonly, perhaps, they contain chemicals somewhat diverse, though of related character; every individual has a great number of such pairs with diverse chemicals in the two packets.

When the organism becomes a parent,

these sets of packets are distributed to the offspring according to a simple plan. The laws of heredity are in the main simply the rules of distribution of the packets. One parent gives to any particular offspring one packet only of each of its pairs. The other parent supplies the corresponding second packet of the pair, so that the offspring has again the full complement of pairs. The first of the rules of distribution discovered was the so-called Mendelian Law; it is the rule according to which the two packets belonging to the same pair are distributed. But when we take into consideration the inter-relations of packets belonging to different pairs, a whole set of rules is discovered covering the distribution of all the packets. These have been worked out in recent years; they are

of equal importance with Mendel's law. In essence all these laws are simple; any set of beads or buttons can readily be put through the same simple operations, and then they yield the same rules that we call the laws of heredity. The only way to grasp these laws is to arrange a set of objects in the way the genes are arranged and to put them through the simple movements followed by the genes; attempts to understand them in any other way are futile. The movements of the genes are at least as important to man as the movements of the planets; in time every school will possess a mechanical model that shows them. The laws of inheritance are not immediate consequences of some fundamental physiological principle, but of the arrangement of the packages of chemicals and their method of distribu-

tion. For genes located in different parts of the chromosomal system the rules of inheritance are somewhat diverse. Some of the genes are not paired, so that they yield a set of rules very different from those followed by others. Where the arrangement of the genes is different, or where there is a different type of distribution, nothing resembling Mendelian inheritance occurs. Such is the situation in the great number of organisms reproducing from a single parent. The dragging effects of tradition are seen in the fact that text-books of heredity still appear in which inheritance is dealt with abstractly, the genes and chromosomes and their products in development being relegated to a special chapter entitled " Mechanism." This is like treating of digestion independently of the digestive secretions

and organs, leaving these to a supplementary chapter. The "Mechanism" of inheritance and development has become the body and substance of the matter.

As the rules of inheritance work out in most cases of biparental reproduction, every germ cell gets a different combination of the packets of chemicals from that obtained by any other, so that, in consequence, every individual starts out as a different combination of chemicals from every other. This makes prediction of results more hazardous in this field than is sometimes represented. Any correct notion of the relation of environment to heredity depends on proper knowledge of how these packets of chemicals operate in producing the developed organism. This knowledge is obtained in two ways. One is by

direct study under the microscope of the changes that occur during development, with experiments on the developing embryo. The other is by interchanging the different packets of chemicals and noting the consequences. In certain organisms it has become possible by proper mating and breeding to control the distribution of the packets almost as if they could be picked out and moved about by hand; this is essentially what is done by Morgan and his associates in their classic work on Drosophila.

Substituting one or more packets for others is found to change the characteristics of the organism produced; different sets give, when they develop, even under similar environments, different physical, mental and moral peculiarities. The first precise discovery made was,

essentially, that when a single one of the packets is exchanged for another, some later character is changed. So changing one packet alters the colour of the hair from black to red; or changes the eye colour from blue to brown; or makes the organism short instead of tall; or even changes a person from a normal individual to a feeble-minded one; or the reverse. Characters changed by altering a single packet were the so-called "unit characters" of Mendelism.

These facts—the relation of single packets to particular later characteristics—gave rise to a general doctrine, a philosophy of heredity and development, a doctrine which has had and still has a very great influence on general views of life. It is to this doctrine that the prevailing ideas as to

the relation of heredity and environment, as to the relative powerlessness of environment, are due. But it has turned out to be a completely mistaken one. This fact has not come to general consciousness; the doctrine continues to be a source of mystification and error. Its complete disappearance would mean a very great advance in the understanding of life.

From the fact that the "unit characters" changed when a single gene changed it was concluded that in some ill-defined way each characteristic was "represented" or in some way condensed and contained in one particular gene. There was one gene for eye colour, another for stature, another for feeble-mindedness, another for normal-mindedness, and so on. Every individual, therefore, came into

the world with his characteristics fixed and determined. His whole outfit of characteristics was provided for him at the start; what he should be was pre-ordained; predestination, in the present world, was an actual fact. Environment might prevent or permit the hereditary characters to develop; it could do nothing more. Heredity was everything, environment almost nothing. This doctrine of the all-might of inheritance is still proclaimed by the popularizers of biological science.

But this theory of representative particles is gone, clean gone. Advance in the knowledge of genetics has demonstrated its falsity. Its prevalence was an illustration of the adage that a little knowledge is a dangerous thing. The doctrine is dead—though as yet, like the decapitated turtle, it is not

sensible of it. It is not true that particular characteristics are in any sense represented or condensed or contained in particular unit genes. Neither eye-colour, nor tallness, nor feeble-mindedness, nor any other characteristic, is a unit character in any such sense. There is, indeed, no such thing as a "unit character" and it would be a step in advance if that expression should disappear.*

What recent investigation has shown is this: the chemicals that were in the original packages derived from the parents—the genes—interact, in complex ways, for long periods; and every later characteristic is a long-deferred

* Seemingly the only remaining possibility of a literal unit character is that some single chemical (for example, epinephrin) appearing in later development is actually present in or produced from a single particular gene, without the co-operation of any others.

and indirect product of this interaction. Into the production of any characteristic has gone the activity of hundreds of the genes if not of all of them; and many intermediate products occur before the final one is reached. In the fruit fly at least 50 genes are known to work together to produce so simple a feature as the red colour of the eye; hundreds are required to produce normal straight wing, and so of all other characteristics. And each of the co-operating packets is necessary; if any one of the fifty is altered, the red colour of the eye is not produced.

And this is what gave rise to the idea of unit characters represented by particular genes. For suppose that one parent has all the fifty packets necessary to produce the red eye, while the other has but 49 of them, the

fiftieth containing some substance that will not work in producing red. Then this parent will not have a red eye, but perhaps a white one, although it differs from the other in but one gene. When these parents produce descendants, the red and white eyes follow in heredity the distribution of that single pair of genes of which one is altered ; wherever the altered gene alone goes appears a white eye ; wherever the unaltered one of the pair, a red eye. So the red colour and the white colour, inherited according to the Mendelian law, were called unit characters : each was supposed due to a single gene.

But actually fifty or more genes are required to produce either, as is discovered when some other one of the fifty is changed off for an altered one. Then, although the first pair of genes is

now unaltered, still the red eye does not appear. Now the eye colour follows the distribution of another pair of genes.

By successively altering genes of different pairs, or by altering genes of two or more pairs in the same parents, certain general relations of the greatest significance are discovered—relations which are commonly ignored. A certain characteristic, such as the red colour, may, with a given pair of parents, follow a given gene, being inherited according to a particular rule —say the "typical Mendelian" rule. In other parents it follows a different gene, and is inherited in a different way—perhaps as a "sex-linked" character. There are fifty or more separate and independent ways by which the character red can be altered,

and each yields a somewhat different rule of inheritance. Or in the same individual two or more of the genes affecting colour may be altered; then the colour is no longer inherited as a "unit character"; its inheritance is now of the "multiple factor" type. In some cases it will follow the rules for two-factor cases; in others for three, and so on indefinitely, until the inheritance may not be distinguished from the "blending" type. Such cases are typical. The fact that in an observed instance a characteristic is inherited as a "unit character" does not show that in other cases it will be so inherited. If a characteristic is observed in a given case to be inherited as a sex-linked character, we cannot be certain that it will be sex-linked in other cases. If it is recessive in some

stocks, it may be dominant in others. Feeble-mindedness appears to be inherited at times as a "unit character"; although nothing can be more certain than that hundreds of genes are required to make a mind—even a feeble mind. It is not surprising that absence or alteration of some one necessary chemical should leave the mind imperfect; this is all that is shown by "unit character" inheritance. Doubtless feeble-mindedness is produced in hundreds of different ways—some sorts heritable according to one set of rules, others according to other sets of rules. Colour-blindness in man appears in some cases to behave as a sex-linked character; this does not make it certain that in other cases it will do so. It is a general truth that, even though we have worked out the precise method of

inheritance of a characteristic in a given stock, we cannot be certain that this same characteristic will be inherited in that way in another stock. It all depends on which particular one or more of the hundreds of genes on which the character depends is diverse in the two parents. It is a commonly-received dogma that if the two parents are defective in the same hereditary characteristic, all the offspring will have this defect. But this need not occur. It will be true only if the defective characteristic is due to a peculiarity of the same gene in the two parents. Where it is due to defects in different genes in the two parents, then the latter supplement each other, and none of the offspring have the defective feature ; such a situation may be readily brought about in animals. Heredity is not the

simple, hard-and-fast thing that old-fashioned Mendelism represented it. Further, more attentive observation has revealed that any single one of the genes affects, not one characteristic only, but many; probably the entire body. The idea of representative hereditary units, each standing for a single later characteristic, is exploded; it should be cleared completely out of mind.

Obviously, these considerations have practical bearings. Students of heredity, like other men, are disposed to make the most of their achievements: to dwell upon what they know, what they can do, what they can predict. They have, indeed, achieved much; the last twenty-five years have made greater advance in the knowledge of heredity than had all the ages before. But

recognition of limitations is as valuable as other sorts of knowledge; realization of what we cannot do is as necessary for correct guidance as realization of what we can do. Every pair of human parents contains thousands of pairs of the packets of chemicals on which development depends. From these a set is drawn almost at random (subject to the condition that one packet is taken from each pair possessed by each parent); this constitutes the heritage of the child. Any pair of parents may thus produce, not merely thousands, but millions, of different combinations, each yielding a child of different characteristics. There is no way of controlling the combinations that shall enter into a child of given parents; there is no prospect that there ever will be. It is, therefore, impossible to

predict what kind of offspring will be produced by a given pair of parents—save in a few respects, in cases where the constitution of both packets of a particular pair are known for each parent. If both parents have the corresponding pairs defective in the same manner—lacking, for example, something required for producing a normal mind—then their children will be all defective like the parents ; feeble-minded parents will produce feeble-minded children. But if, as may well be the case, the feeble mind is due to defects in different packets in the two parents, then all experimental breeding shows that the two parental stocks may supplement one another, so that the defect will not appear in the offspring. The characteristics that are predictable are extremely few ; a new combination is produced

with every child. No pair of parents has a sure thing as to the high character of their prospective offspring. There are few parents, at least among those not falling in the definitely pathological group, of whom it can be predicted that their children must be worthless.

The genes then are simply chemicals that enter into a great number of complex reactions, the final upshot of which is to produce the completed body. The characteristics of the adult are no more present in the germ cells than are those of an automobile in the metallic ores out of which it is ultimately manufactured. To get the complete, normally-acting organism, the proper materials are essential; but equally essential is it that they should interact properly with each other and

with other things. *And the way they interact and what they produce depends on the conditions.*

This is shown to be true both through observation of the processes of interaction, in development; and through experimentation with diverse conditions. Under the microscope the set of genes —the chromosomes of the egg—are seen to go promptly to work. They suck up a quantity of material from the surrounding cytoplasm, becoming balloon-like. They transform this chemically, then give it off again into the cell body, visibly changed into something new. Diverse new substances thus formed move into different regions of the egg. By cell division some of the newly manufactured substances are passed into one cell, others into another. Thus the cells become

diverse; the different structures of the body are being made. This is repeated in each cell generation, the chromosomes by interaction with the cytoplasm changing the substance of the cells, until finally nerve, muscle, bone, gland and other tissues result. But in all this interaction of the chromosomes to produce new cytoplasmic materials, the chromosomal materials—the genes—are not themselves used up. Always a reserve portion of each chromosomal substance is saved; so that none of them are lost, and their number does not decrease. And at each cell division every reserve packet is divided, half of it going to each of the two cells, where it grows to full size. So every cell of the body continues to contain the entire set of the parental chemicals, just as the egg

did.* The differences between the diverse cells of the body are, therefore, not in these substances, not in the genes they contain, but in the remaining part of the cells, the cytoplasm. These differentiations have been produced by the interaction of the genes with the cytoplasm. It is in this way that the complex adult body, with its typical pattern of structures, is produced.

In producing these structures, the genes interact, not only with each other, with the cytoplasm, with the oxygen from the surrounding medium, and with the food substances in the cytoplasm; but also, what is most striking and important, with products from the chemical processes in neighbouring cells. Necessarily, then, this complicated inter-

* Like almost any biological generalization, this statement is subject to exceptions. But for most parts of most organisms it is true.

action depends upon many conditions, a dependence that becomes manifest as methods of experimentation become precise. The process of development shows itself not to be stereotyped, as at first appears to be the case ; it varies with changes in conditions. What any given cell shall produce, what any part of the body shall become ; what the body as a whole shall become—depends not alone on what it contains—its "heredity"—but also on its relation to many other conditions ; on its environment.

This is well shown in the development of our close relatives, the amphibia. The frog or salamander begins as a single cell, which divides into two. Usually one of these two produces the right half of the body, the other the left half. But this depends on the

relation of the two cells to one another ; separate them, and each produces an entire animal instead of half a one Somewhat later in development the young salamander has become a sphere of many small cells, differing in different regions. Under usual conditions it is possible to predict what later structure each cell, each region of the sphere, will produce. The cells that will produce brain, eye, ear, spinal cord, skin, can be pointed out. The predicted process occurs with such regularity as to appear stereotyped.

But study shows that this is because the effective environment is usually the same for any given cell. What any cell shall become depends on the conditions surrounding it, on its relation to the other cells. Development, it turns out, is a continual

process of adjustment to environment. The recent brilliant work of Spemann shows that at a certain point in the developing mass of small cells (just in front of the blastopore) there begins a differentiating influence, whose further nature we do not know. This creeps from cell to cell, forwards and sideways, determining the type of chemical processes that shall occur in each cell, in such a way as to fit and conform the structures produced by that cell to those produced by the cell differentiated just before it. In this way the whole mass of cells diversifies into the pattern of the later structures. Here the cells differentiate into spinal cord, next into medulla, next into midbrain, here at the side into eye ; here into ear ; still farther into skin. But if before this happens the disk of cells is cut off and

turned sideways, or completely round, the differentiating and adjusting influence creeps through it from the same point as before, but now in a different or reversed direction, so far as the cells are concerned. The cells that were to have formed skin produce spinal cord; those that would have produced eyes may form midbrain, or skin or ear, depending on just how they are placed with reference to the spreading differentiating influence; and so of the others. Or, transplant a small piece of prospective skin to the centre of the eye-producing region; it now transforms into eye instead of into skin; transplant a prospective ear to another region, and it becomes skin or spinal cord, as its place in the pattern requires. It is proved that any particular cell may become part of any one

of these structures, depending on its relation to the other cells. There comes a time after the wave of differentiation has gone over them, when they can no longer be altered; their fate has been accomplished. This occurs at different developmental periods in different organisms, and in different parts of the same organism, giving rise to confusing and paradoxical situations; what is true for one organism or part is at the same period not true for another. But until the wave of differentiation has passed, development is adjustment to the conditions. What part of the body a cell shall produce is not determined alone by its genes, by what it contains, but equally by the conditions surrounding it.

In later stages we know something of the nature of the cell products which

help determine what the parts of the body shall become. There are a vast number of such intermediate products, necessarily produced before the adult structures can be made ; some of them are the internal secretions, hormones, or endocrine products, which are now the reigning sensation in biology. These are the relatively early and simple products of the chromosomal genes in their interactions with each other and with other things. A difference of a single chromosome, it can be proved, causes in early stages two diverse hormones to be produced in two individuals ; and this gives rise in turn to diversity of sex, with the great number of differential details that this includes. The production, distribution, and action of these intermediary chemicals, with the consequent method

of development in the individual, are subject in high degree to change by the surrounding conditions. Already men have learned to draw off these chemicals from one individual and introduce them into another, so altering profoundly its development. Already they have manufactured certain of these products of the genes. How far may this go in a thousand years? The fact that in the products of the chromosomal genes we are dealing with chemicals that can be made, modified, and moved about, as other chemicals are, opens an unlimited field for progress in the control of development. There is no *a priori* reason why anything that may be done by a chemical produced from an individual's own genes may not be done equally by a chemical introduced in some other way. Short-

comings due to defective genes are essentially as subject to supplement and remedy as are other defects.

Not only what the cell within the body shall become, but what the organism as a whole shall become, is determined not alone by the hereditary materials it contains, but also by the conditions under which those materials operate; or by other materials that may be added later. Under diverse conditions the same set of genes will produce very diverse results. It is not true that a given set of genes must produce just one set of characters and no other. It is not true that because an individual inherits the basis for a set of characteristics, that he must have those characteristics. In other words, it is not necessary to have a certain characteristic merely because one

"inherits" it. It is not true that what an organism shall become is determined, foreordained, when he gets his supply of chemicals or genes in the germ cells, as the popular writers on eugenics would have us believe. The same set of genes may produce many different results, depending on the conditions under which it operates. True it is that there are limits to this; that from one set of genes under a given environment may come a result that no environment can produce from another set. But this is a matter of limitation, not of fixed and final determination; it leaves open many alternative paths. And even the limitations lose their sharp definition when we contemplate the possibility of introducing other chemicals among those produced by the original genes. Every individual

has many sets of "innate" or "hereditary" characters; the conditions under which he develops determine which set he shall bring forth. The characteristics that appear under training are as much inherited characters as are those appearing under other conditions; for the conditions help determine the characters in the one case as in the other. These sweeping statements are substantiated by precisely-known facts in many organisms.

To grasp the bearing of these facts, one must keep in mind what sort of characteristics are called hereditary or inherited. If of two sets of individuals of diverse stock, developing under the same conditions, one has the characteristic A, the other the characteristic B, then A and B are said to

be inherited. The development of each, under the conditions, is due to some peculiarity of the germinal constitution of the stock in which it occurs. When it is found (as will be the case) that, in crosses, A and B behave in accord with Mendelian rules, the test for inheritance is complete.

Following this usage, we may turn to certain inherited characters. In that animal whose heredity is better known than is that of any other organism, the fruit fly, individuals occur with hereditary abnormalities. The abdomen is irregular, deformed; the joints between the segments are imperfect. This is sharply inherited as a sex-linked character, so that it is known to be due to a peculiarity of one of the genes in the x-chromosome. If the father has this abnormality, all

his daughters inherit it, but none of his sons do so. The daughters hand it on to half their sons and half their daughters, and so on.

But the fruit flies in the laboratory usually live in moist air and this inheritance appears under those conditions. If they are hatched and live under dry conditions the abnormality doesn't appear—even in those daughters which indubitably inherit it. Clearly, it is not necessary to have a characteristic merely because one "inherits" it. Or more properly, characteristics are not inherited at all; what one inherits is certain material that under certain conditions will produce a particular characteristic; if those conditions are not supplied, some other characteristic is produced.

Similarly, some of the fruit flies

inherit, in the usual Mendelian manner, an inconvenient tendency to produce supernumerary legs. But if those inheriting this are kept properly warmed they do not produce these undesirable appendages. In the cold, only those individuals acquire the extra legs that have inherited the gene to which such are due; but even they need not do so, if conditions are right. In the same animal, some individuals have fewer facets in the compound eye than do others. The number of facets is found to be hereditary, in the sense that under the same conditions parents with few facets produce offspring with few facets, in the Mendelian manner. But the number also depends on the environment; individuals with the same inheritance show different numbers of facets, depending on the temperature

at which they develop. If the individual A has a certain number of facets, while B and C have a different number, the same in both, it may be found that the difference between A and B is due to inheritance, while the same difference between A and C is due to environment. Such facts are typical; differences due in one case to heredity may be due in another to environment. There is no characteristic distinction between hereditary diversities and environmental diversities; whether a given instance belongs to one or the other category can be determined only by experimental analysis.

Other known cases illustrate the effect of the environment in altering the totality of the organism, its entire personality, as it were. Many years ago there was discovered in Mexico a

salamander that lives throughout its life in water, has a heavy, broad body, a tail flattened for swimming, and external gills. In this condition it becomes mature, lays its eggs in the water; produces young that inherit its characteristics, and finally dies. This continues for generation after generation. A number of these axolotls were kept for years in the Zoological Gardens at Paris; they showed the inherited characteristics above set forth. Breeding experiments on these animals would show these characteristics to be inherited in the usual Mendelian manner.

But after years in which these were the only inherited characteristics that they were known to possess, certain different environmental conditions were brought into action, and thereupon, to

the astonishment of the observer, the axolotls developed a new set of inherited characteristics, a new and diverse personality. The external gills disappeared, the body became smaller, slender, and of a very different shape, the animals came out on the land and remained there, breathing air. They now became mature in this amblystoma condition, laid eggs, and produced offspring—which again, under these conditions, developed into land animals of the same sort; and this, too, may continue for generation after generation. The inherited characteristics are now these land characters; these are, in detail, inherited in the typical Mendelian manner.

Here we have two extremely different sets of inherited characteristics; which one shall appear is determined by the

environment under which the organism develops. If "hereditary" means dependent for development on peculiarities of the germinal constitution (the sense in which it is employed) both sets are hereditary. If "environmental" means dependent for development upon peculiarities of the environment, both sets are environmental. Any characteristic requires for its production both an adequate stock of chemicals and an environment adequate for its production through proper interaction of these chemicals with one another and with other things. In these senses all characteristics are hereditary and all are environmental, but no characteristic is exclusively hereditary or exclusively environmental.

Beyond all other organisms, man is distinguished by the possession of many

sets of inherited characteristics; the decision as to which shall be produced depending on the environment. The axolotl may be compared to an uneducated man, the amblystoma to an educated one. The educated man has characteristics very diverse from those he would possess if uneducated. We say, when we think of this fact, that these are acquired characters, environmental characters, due to education. This is correct; but there is a tendency to go farther and say that these are not inherited characters. This is a mistake—unless we are prepared to cancel *in toto* the designation "inherited characters." The characteristics of the educated man are his native, inherited characters, just as truly as are any that he has. For all his characteristics depend on the con-

ditions under which he develops, and would be diverse under different conditions, just as is true of the characteristics that develop under education. And the characters developed under education depend upon the hereditary materials derived from the parents, changing as these materials are altered, just as do all others. "Hereditary" has no consistent meaning other than this. The teachings of genetics may be summarized in Aristotle's saying—"the nature of man is not what he is born as, but what he is born for"—paraphrased perhaps into the form "the inheritance of man is not alone what he is born with, but what he can develop."

Why it seems paradoxical to call the characteristics developed under education inherited, while we make no difficulty in thus designating the colour of

the eyes and the stature, lies in certain practical difficulties, not in any difference of principle. In the group of organisms to which man belongs there is an early period in which it is practically difficult to change effectively the conditions under which the organism develops, because it is enclosed within the mother's body, or within a resistant egg shell. So we have gotten accustomed to calling inherited those characteristics which are determined before it leaves its mother's body or the egg, while those determined later are called acquired characters. But this is an artificial distinction, based on practical considerations. In many organisms there is no such distinction into two periods ; in them it is possible to alter the conditions at any period, even the earliest. And when this is done it is

found that all the characters depend on the conditions ; that such fundamental characters as " the number of eyes an animal has " or " the position of the eyes in the body " may be altered. In fish, for example, two eyes, one at each side of the middle line, form as distinctly an inherited characteristic as in man, yet fish can be subject so early to changed conditions (as Stockard and others show) that the animal has a single median eye instead of two lateral ones ; and many other equally striking changes are producible by changes in the chemical environment. If the fish lived continuously in these conditions they would regularly inherit a single median eye ; the two lateral eyes would be looked upon as a rare abnormality, produced by special conditions and not inherited. In truth, all characters are

as certainly due to the conditions of development as to the materials of the germ cells.

If there were not practical difficulties in the way, similar fundamental changes of structure could be made in man or any of the higher animals. In these higher creatures, a time comes, before development stops, in which it is possible to change the conditions ; that is, after what we call birth. And then it is found that changing the conditions does change the characteristics that later develop—exactly as the characteristics of the fish are changed by changing the conditions. We call this process education. If we could give the same education for many generations to a number of different human families, we should find that the characteristics resulting from education are inherited

characteristics in the same sense as are colour of eyes and form of head. Under the same education they would differ in individuals of diverse stock; and in crossing they would follow Mendelian rules, as do physical characters.* Every creature has many inheritances; which one shall be realized depending on the conditions under which it develops; but man is the creature that has the greatest number of possible heritages. Or, more accurately, men and other organisms do not inherit their characteristics at all. What their parents leave them are certain packets of chemicals which under one set of conditions produce one set of characters, under other

* Obviously, nothing in the text relates to the effect of education on the descendants of the educated person; that is, to "the inheritance of acquired characters." The propositions set forth are equally valid whether there is or is not such effect on the descendants.

conditions produce other sets. In man, the number of diverse sets that may thus be produced is very great; although it is, of course, not unlimited. But what the limitations are cannot be stated from general biological principles or from what we know of any other organisms; they can be discovered only by concrete studies of man himself.

Adequate recognition of these facts and principles, which appear fully established by the advance of genetics, would greatly alter some of the current discussions and attitudes on the relation of biological science to human affairs. The biologist is pained to find that the medical man resists the introduction of the concept of heredity into the domain of disease. This is because of the current fallacy that what is hereditary is certain, fixed,

unchangeable. Very properly the medical man rejects that, in its application to disease. But with the recognition that to assert that a thing is hereditary signifies merely that the organism has received such a constitution as to produce it under given conditions, all such ground of objection vanishes. This does not deprive of significance recognition of the part played by heredity in medicine ; which is but recognition of constitutional differences that have origin in diversities of the germ cells. The individual who may produce an inherited defect under certain conditions need not produce it under others. Some individuals receive a constitution which resists disease under conditions in which others succumb to it. Some respond in one way to particular therapeutical agents,

others in another way, depending on their hereditary genes. It is only against what Davenport has characterized as purely impersonal medicine that the implications of genetic science lie.

The same fallacy reappears in discussions of racial problems. The recent immigrants into the United States show certain proportions of defective and diseased persons; and we are informed that "these deficiencies are unchangeable and heredity will pass them on to a future generation." There is no warrant in the science of genetics for such a statement; under new conditions they may not appear. It is particularly in connection with racial questions in man that there has been a great throwing about of false biology. Heredity is stressed as all-powerful;

environment as almost powerless: a vicious fallacy, not supported by the results of investigation. We are warned not to admit to America certain peoples now differing from ourselves, on the basis of the resounding assertion that biology informs us that the environment can bring out nothing whatever but the hereditary characters. Such an assertion is perfectly empty and idle; if true, it is merely by definition: anything that the environment brings out *is* hereditary, if the word hereditary has any meaning. But from this we learn nothing whatever as to what a new environment will bring out. It may bring out characteristics that have never before appeared in that race. What the race will show under the new environment cannot be deduced from general biological principles. Only

study of the race itself and its manner of reaction to diverse environments can give us light on this matter.

All characteristics then are hereditary in that they depend upon the germinal material and change as that material is altered. All characteristics are likewise environmental, in that they depend upon the conditions under which development occurs, and change as those conditions are altered. The concepts of the hereditary and the environmental cannot properly be employed in the absolute way now practised, as distinctive of particular characteristics. But their respective rôles can nevertheless be disentangled with precision if they are applied, not to characteristics in themselves, but to the diversities between particular concrete cases. Is colour of skin a

hereditary or an environmental character? As to skin colour in general, no such distinction can properly be made. If A has lived indoors and is light, while B has lived under the tropical sun and is dark, the difference between them may be purely a matter of the conditions under which they have lived; their hereditary constitutions may be alike as to this matter; the difference is environmental. But C, who has lived indoors with A, is nevertheless dark; the difference between A and C is then a matter of heredity; the two have received diverse germinal materials from their parents. The same situations prevail among things inorganic. To employ Erwin Baur's instance, is the degree of hardness shown by samples of paraffin a matter of their constitution or of the conditions?

If we compare two pieces from the same lot, one at a temperature of 20 degrees, one at 35 degrees, the difference in hardness is a matter of the conditions. But if at the same temperature we compare a sample of paraffin that melts at 25 degrees with one that melts at 40 degrees, the difference in hardness is a matter of constitution. If now we inquire as to the origin of the difference in constitution, tracing the two samples perhaps to oils from different regions, we embark upon an investigation strictly comparable to research in heredity.

Such analysis must be applied to all cases. Though stature is always dependent both upon hereditary constitution and upon environment, the difference in stature between Jones and Smith may be purely a matter of heredity, the difference between the

same Jones and Brown purely a matter of environment. If there is clarity as to what comparison is made, there need be no ambiguity as to what is due to heredity, what to environment. In accounts of genetic experimentation, such comparison is commonly not explicitly set forth, but it is implicit, and if adequate data are given, it can be supplied by the reader. For clearness of thought this must always be done.

By statistical extension, such comparison may be made for large classes. But it is essential here as elsewhere to keep in mind that we are dealing with comparisons between concrete cases, not with propositions of absolute validity. Are the differences between men due more to heredity or to environment? If we compare ourselves with our

ancestors of 10,000 years ago, they are due mainly to environment—if it is correct, as generally admitted, that the fundamental constitution of the stock has not appreciably changed since that time. If the comparison is of ourselves with the Bushmen of South Africa, possibly the differences are mainly due to heredity. If the comparison is between the diverse races of Europe, or between the individual citizens of the United States, the answer is to be obtained only from a much greater amount of precise study, with critical statistical treatment, than has yet been made; and there is reason to think that it would signify little when reached, since it would be merely an average of a very great number of individual comparisons, many falling to one alternative, many to the other. Cer-

tainly the answer is not to be deduced from any alleged biological principle that the characteristics of organisms are due to heredity and not to environment.

III. The Advancement of Man

Such being the biological background, what of the advancement of man? Through his manifold alternative inheritances, what a man shall become is determined by the conditions under which he develops to a greater extent than in any other organism. The lot of given individuals and societies is enormously alterable and improvable by change of conditions, by inventions, by increase and dissemination of knowledge. The tremendous changes in the state of the Germanic races in the last 20,000 years have been brought about, for better or worse, by this

means; equally great changes can, therefore, be similarly brought about in this or other races. These are facts of human biology that cannot be altered by anything learned of the biology of other organisms. All groups of organisms have some common features; but every group has, too, its distinctive features. When the biologist, from his knowledge of other organisms, is tempted to dogmatize concerning the possibilities of human development, let him first ask himself: How correctly could I predict the behaviour and social organization of ants from a knowledge of the natural history of the oyster? Man differs from other organisms in these respects certainly as much as the ant does from the oyster; for these distinctive aspects of his biology only the study of man himself is relevant.

There is nothing in the general principles of biology which says that increase and diffusion of knowledge shall or shall not do away with warfare, solve the problem of over-population, and otherwise bring to realization the dreams of reformers. These are questions of the special biology of *Homo sapiens*, on which knowledge of Amoeba, the oyster and the ant have no bearing.

But environmental changes have another class of effects: through their selective action they alter the constitution of later generations. As conditions become easier, combinations of genes that would have been eliminated survive, develop and propagate, so that the later population contains less resistant individuals than did the earlier; saving the tubercular results in a population less resistant to tuberculosis.

This effect of improved conditions has given rise to a pessimism of unrelieved blackness, thorough-going, irremediable. Every improvement in conditions, it holds, inevitably weakens the stock. By a dreadful paradox, present amelioration means later deterioration. The more rapid the upward movement in conditions, the more headlong the downward plunge into degeneration.

Every important cultural improvement certainly does shift the incidence of selective elimination. Nothing in the history of the race has so preserved and multiplied the weak and (previously) unfit, as did the Promethean bringing of fire into the service of man. The invention of clothing, of tools, of social organization, of writing, have had the same degenerative effects. Com-

pared with the disastrous results of these, vaccination for smallpox and typhoid, abolition of conditions that bring plague, cholera and yellow fever, though tending to fill the population with non-resistant types, can have been only moderately degenerative. Does biological science support and demonstrate this paradox?

If it is certain that the downward racial tendency induced by the changed selective action is more potent than the immediate amelioration resulting directly from the improved conditions, then, indeed, is man headed for destruction; for it is idle to attempt to so alter his nature that he will not improve his living conditions. No one will propose to go back to the days of no fire and no clothing. But nothing demonstrates that the softening due

to the changed selective action is more potent than the directly beneficial effects of such inventions. No one knows that the vigour of later generations is not increased by the greater well-being of the bodies in which the genes live and develop. There is no certainty that the invention of fire, clothing, social organization, and vaccination have not augmented the well-being and staying-power of the race.

On the other hand, there are a few social practices that recognizably and directly work toward racial degeneration; these should obviously be stopped. Such are the freedom and encouragement of reproduction among the feeble-minded, the criminal, the insane. But it is a far cry from these to the inventions that have improved the lot of all mankind.

But such negative and palliative eugenic measures, directed against the obviously pathological, leave untouched the futility, incompetence and unreason that have of late brought gigantic disaster. There is a positive eugenic programme, designed to meet this problem. What are its opportunities?

Under the usual present conditions, omitting the clearly pathological, some combinations of genes produce desirable individuals, others undesirable ones. It is to the prevalence of the latter that the troubles of humanity are due. Shall we not bring it about that in future generations only the individuals shall develop that have the better assortments of genes?

Insight into the difficulties and possibilities of this programme demands the taking of a wide and long view of

the organism that we wish to improve. Man, or any of the complex animals, is to be looked upon as a single organism, temporarily divided into pieces or individuals. These pieces reunite at intervals and again separate. The great organism thus forms a network. The enduring parts of the network are the genes. They form the continuous strands of the net, living through from generation to generation, and taking part successively in the formation of the bodies of many different individuals. The number of strands or genes in the entire network is very great; much greater than the large number present in any individual. A different combination of strands is present in every individual.

As the generations pass the combination of strands in a given individual

separates repeatedly into two halves; each half unites with a corresponding half from another individual to make a new combination for the next generation. From each new combination of the strands an outgrowth appears; this is what we call an individual. But this outgrowth is not permanent. After a time it decays and drops off, while the combination of genes that formed it separates and passes into new combinations, yielding new individuals.

Thus upon this great immortal vine the individuals hang like grapes from a pergola, each individual constituted of all the strands that the netted vine happens to have at that point. What the fruit becomes depends, under given conditions, upon which of the strands go into it; size, form, colour, structure, vigour, activity, type of behaviour,

senses, power of learning, power of reasoning—all depend, other things being equal, on the strands that are present.

Thus we find that, in all organisms, some of these combinations produce fruits that are better fitted to the prevailing conditions of life than are others. Some in man are vigorous, sensible, efficient, valuable to themselves and others. Others are defective, weak, foolish, worthless, injurious to themselves and to others. What the eugenecist desires to do is to save, propagate and multiply the good combinations, letting the poor ones disappear.

In the lower animals and plants there is what might be called a special device for carrying out precisely and regularly this eugenic problem. Any one of the

fruits on the vine—the individuals—can multiply without forming new combinations of genes. It simply divides frequently, or gives off small pieces, producing thus a great number of individuals like itself—all with the same identical combination of genes. An individual of vigour thus brings forth thousands like itself; in time almost or quite the entire population may consist of this single type, while the weak individuals wither and disappear. This happens on a grand scale in the lower organisms under natural conditions.

By the intervention of man, supplying special conditions, almost any type of individual may thus be induced to multiply till an entire population consists of that single kind. This is what has happened in most of the cultivated

fruits. Once a good combination of genes is obtained, it is preserved and propagated unchanged.

This is what the eugenicist desires to do in man. But in man and other higher animals no combination is permanent. None ever lasts beyond the life time of the single individual. No individual can be multiplied in such a way as to retain the same combination of genes. No matter how vigorous, how well adapted to the conditions, how valuable from every point of view, every combination must disintegrate and a differently constituted one must appear for the next generation. The new one may be less vigorous, less valuable in every way, but it must appear in place of the old one. Indeed, the outstanding individuals, the geniuses, are always rare special com-

binations, occurring, according to the laws of permutations, only once in thousands of instances. When they are taken apart, the new combinations made are almost certain to be the commoner types, less valuable than their parents. What occurs in such cases is seen when one of the valuable fruits—a fine variety of apple or orange —is allowed to reproduce by seed, forming thus new combinations of genes. Among the offspring are many types, mostly inferior ones, thorny, irregular, weak plants with worthless fruits. Almost never is one produced that equals the parent. This is the sort of thing that occurs regularly in man.

But the same is true for the poor combinations. They, too, must disintegrate and pass into new groupings; and now the offspring may be better

than the parents; certainly they will be diverse. And from the large population of commonplace types appear continually, as the generations pass, a few rare ones—for genius or for inferiority—then after a generation these drop back again into the great reservoir.

So, though in lower organisms the valuable types may be directly saved and propagated, this cannot be done in man. The genes must continually change their combinations, now producing a superior individual, now a commonplace one, now an inferior one:

"Only while turns this wheel invisible
No pause, no peace, no stopping place can be;
Who mounts will fall, who falls may mount—
the spokes
Go round unceasingly."

So far as the genes go, reincarnation is a literal fact; one gene in its time

plays many parts in persons of the most diverse kinds :

> " Who toiled a slave may come anew a prince—
> Who ruled a king may wander earth in rags."

The disappearance into the melting pot of the rare and excellent combinations has long been a ground for criticism of the way the universe is run. The author of Ecclesiastes hated all the labour that he had taken under the sun because he should leave it to the man that should come after him, " and who knoweth whether he shall be a wise man or a fool ; yet he shall have rule over all my labour wherein I have shown myself wise under the sun." The Eugenicist agrees with these animadversions, and wishes to change the system which justifies them ; he desires to continue the combinations

that have proved valuable, and to suppress the others.

If uniparental reproduction could be brought about in man, as it is in apples and oranges, this could be done. And the process that underlies this—the division of a single combination so as to produce identical individuals—does at times occur in man, though in a way that is not under control, and that does not help in attaining the eugenic ideal. In the production of identical twins one of the fruits of the vine divides into two that have the same combination of genes. But this occurs but once, and at so early a stage in development that there is no way of knowing whether the combination duplicated is a good one. What the eugenic plan requires is that the adult, after he has shown his value, should be multiplied without

change of genetic combination. If this could be done, man would have his fate in his own hands. He could multiply the desirable combination until the entire population consisted of that type.

Of course, he would then come squarely against the question as to what kind of individual should thus be allowed to multiply and inherit the earth. There is little doubt that, as Mr. Bertrand Russell* suggests, the ruling class, whatever its character, would be the one allowed to prevail. As they now attempt to suppress the opinions that do not agree with their own, so with this efficient weapon in hand they would radically wipe out types holding other ideals. With the

* Russell, *Icarus* (Kegan Paul and Co., Ltd., London ; E. P. Dutton and Co., New York).

capitalist class in complete possession, the world would become uniform; doubtless more comfortable; certainly less entertaining as a spectacle. The unexpected, the exciting, the amusing, the melodramatic, would disappear. With this would go poetry, art, literature. The human orchard would consist of well-trimmed fruit trees in set rows, each bearing a crop of succulent fruit.

Unfortunately or fortunately (whichever one's philosophy inclines him to hold), this cannot be done in mankind. If an ingenious inventor were set to devise a system for the purpose of heading off completely anything of this sort, he could hardly produce one so effective as the one found in nature. This might rather seem devised to the end of giving the greatest possible

variety; of yielding the extremes of diversity at any one time; of inducing most thorough-going and continuous changes as generations pass. Personified nature might well be held to abhor uniformity and constancy, for the higher organisms.

Is there no way by which the Eugenicist can circumvent this propensity of nature? Is there no way to substitute uniform excellence for extreme and heterogeneous variety?

Quite aside from the difficulty of getting agreement as to the human type that is to prevail, the enterprise is extremely difficult even from a merely technical standpoint. But a certain amount of effect could be produced by operating on statistical principles. While it is not certain that given superior parents will produce superior

offspring, nor particular inferior parents inferior offspring, it is true in the long run that a million superior parents will produce, on the whole, offspring of higher average grade than those produced by a million inferior parents.

If, therefore, on a grand scale, the superior parents could be induced to produce more offspring, the inferior ones fewer, this might on the whole raise very slowly the level of human kind. The uncertain element here is the great reservoir of genes held by the undistinguished individuals, constituting nine-tenths or more of humanity. From these come, through kaleidoscopic recombination of genes, a large proportion of the unusual individuals that occur—both those that are superior and those that are inferior. If all these unusual individuals, above

and below the commonplace, could be cut off as parents, they would be replaced in at least large measure from the unusual progeny of the large commonplace group.

But whatever eugenic measures are attempted, so long as biparental inheritance is kept up, the variety, the surprises, the perplexities, the melodrama, that now present themselves among the fruits of the human vine will continue. Capitalists will continue to produce artists, poets, socialists, and labourers ; labouring men will give birth to capitalists, to philosophers, to men of science ; fools will produce wise men and wise men will produce fools ; who mounts will fall, who falls will mount ; and all the kinds of problems presented to society by the turns of the invisible wheel will remain.

They may be softened by improvement of conditions, by increase of knowledge, and perhaps by selective eugenics; but they will not disappear so long as biparental reproduction continues.

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